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In reply refer to: **G-41-X49**

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Telephone No.: (404)894-2429
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The subject report is forwarded in conformance with the contract/grant specifications.

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Sincerely,

Wanda W. Simon
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FINAL TECHNICAL REPORT

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The goal of this research project was to study the spatiotemporal and stochastic dynamics of systems comprised of coupled arrays of nonlinear elements using an experimental method employing analog VLSI hardware. This is part of an ongoing initiative our nonlinear dynamics group to exploit the highly developed, sophisticated, and flexible technology of semiconductor electronics for studying a variety of many degree of freedom dynamical systems. Under the AASERT grant, a set of research projects involving the various phenomena of stochastic resonance, mutual synchronization, and spatiotemporal chaos were designed and carried out by Brian Meadows, a graduate student working under the joint direction of professors Bill Ditto (primary advisor) and Kurt Wiesenfeld. Meadows is a U.S. citizen, and received his Ph.D. in Physics from Georgia Tech this spring (June 1998).

Funds from the AASERT grant were used to support Meadows over a three year period by paying his salary, the purchase of some laboratory equipment and associated laboratory expenses, and travel costs associated with his attending scientific conferences. Meadows completed his doctoral dissertation in the spring quarter of this year [1]. He is currently a scientist at the SPAWAR Systems Center in San Diego.

SINGLE THRESHOLD STOCHASTIC RESONANCE IN A DIODE. In a step preliminary to the study of arrays, experiments were carried out on a single-element system. The single element chosen was a diode, which in the stochastic resonance lexicon falls in the category of a single threshold system, as distinguished from either bistable or nondynamical types[2]. Two types of diodes were used as the triggering element: a PN-junction diode (Motorola 1N4001) and a Schottky diode (Motorola 1N5817). These differ substantially in the fundamental physics underlying their operation; however, their I-V characteristics are described the same exponential sensitivity to the input voltage[3]. Experimentally, both types of diodes demonstrated virtually the same response to the application of signal and noise. The data clearly exhibited the characteristic signature of stochastic resonance, a maximum in the signal-to-noise ratio at a nonzero value of input noise. Operating the diode detectors at the optimal noise value yielded approximately 12 dB increase in the output signal-to-noise ratio as compared to driving device with significantly lower noise.

NUMERICAL SIMULATIONS OF BY STABLE ARRAYS. As a theoretical component of the dissertation, large-scale numerical simulations were carried out on a one dimensional chain of Duffing oscillators subjected to a small global periodic drive and variable local random noise terms. These simulations demonstrated that local linear coupling can enhance stochastic resonance. Studies of chains ranging in length from 9 to 512 elements show that the peak signal-to-noise ratio is attained at a particular value of the coupling strength and is proportional to N^2 ; the optimal noise variance was observed to rise linearly with N [4]. (Both of these scaling laws hold in the large- N limit.) These results were experimentally verified by Locher and co-workers in array of coupled diode resonators[5].

STUDIES OF STOCHASTIC VLSI ARRAYS. Recent advances in fabrication technology and CAD tools enable the realization of highly complex digital very large-scale integration (VLSI) logic systems. Digital VLSI provides fast, general-purpose, high precision calculations on symbolic information. In contrast, analog VLSI (aVLSI) exploits the intrinsic device physics to form the computational element, rather than abstract algorithms tailored for digital hardware. Information processing in aVLSI is based on continuous functions of time, space, voltage, current, and charge. This reflects an architectural rather than an algorithmic design philosophy, especially well suited to the goals of our project.

Leveraging these advances in aVLSI, a variety of spatial extended nonlinear systems were fabricated on chips using the MOSIS foundry service. The analog microelectronics approach has the capacity to place thousands of individual elements onto a single device. Specifically, aVLSI detector arrays based on single elements known to exhibit stochastic resonance were designed, fabricated, and tested. The first chip sets used a Schmitt trigger array, and the second used an integrate-fire neuron array. (Individual Schmitt triggers exhibit bistable stochastic resonance; individual integrate-fire neurons are of the single-threshold type.)

The Schmitt trigger chip contained 63 individual Schmitt triggers, 7 rows by 9 columns, with linear nearest neighbor coupling and free boundary conditions. The chip design allowed for experimentally controlled coupling and the ability to adjust the hysteresis window of the Schmitt trigger. Configuring the chip as a zero-, one- or two-dimensional array could be conveniently chosen simply by adjusting the bias on the coupling transistors. The chip design was based on standard scalable design rules making it straightforward to increase the number of elements in future studies [6].

The Schmitt trigger chip experiments demonstrated that periodic signal amplitudes well below the array detection threshold could be recovered by the addition of noise. At the optimal value of added noise, there was a 40 dB improvement in output signal-to-noise ratio of constituent elements (above that achieved with zero added noise). The array exhibited both temporal and spatial locking behavior over a broad range of noise and coupling [7].

In contrast, while the design and fabrication of the chip consisting of integrate-fire elements was completed, there was insufficient time for Meadows to undertake detailed, systematic experiments of this array. That work may be carried out by a future graduate student.

References

- [1] B.K. Meadows, "*Spatiotemporal Dynamics of Stochastic and Chaotic Arrays*", Georgia Institute of Technology, 1998.

[2] K. Wiesenfeld and F. Moss, "*Stochastic Resonance and the Benefits of Noise: From Ice Ages to Crayfish and SQUIDS*", Nature 373, 33-36 (1995).

[3] S.M. Sze, *Physics of Semiconductor Devices*, 2nd Edition (Wiley, New York, 1981).

[4] J.F. Lindner, B.K. Meadows, W.L. Ditto, M.E. Inchiosa and A.R. Bulsara, "*Scaling laws for spatiotemporal synchronization and array enhanced stochastic resonance*", Phys. Rev. E 53, 2081-6 (1996).

[5] M. Locher, G. Johnson and E. Hunt "*Spatiotemporal Stochastic Resonance in a System of Coupled Diode Resonators*", Phys. Rev. Lett. 77, 4698-4701 (1996).

[6] B.K. Meadows, J. Neff, G.N. Patel, W.L. Ditto and S.P. DeWeerth, "*Chaotic and Stochastic VLSI Arrays*" (in preparation).

[7] J.D. Neff, G.N. Patel, B.K. Meadows, S.P. DeWeerth and W.L. Ditto, "*Spatiotemporal dynamics of a stochastic VLSI array*", Proceedings of the 1998 IEEE International Symposium on Circuits and Systems, pp. 542-5 (1998).

Research Articles/Publications by B.K. Meadows (during grant period)

M.E. Inchiosa, A.R. Bulsara, J.F. Lindner, B.K. Meadows and W.L. Ditto, "*Array enhanced stochastic resonance: implications for signal processing*", AIP Conference Proceedings no.375 p.401-19 (1996).

J.F. Lindner, B.K. Meadows, W.L. Ditto, M.E. Inchiosa and A.R. Bulsara, "*Array enhanced stochastic resonance and spatiotemporal synchronization*", Physical Review Letters vol.75, no.1 p.3-6 (1995).

J.F. Lindner, B.K. Meadows, W.L. Ditto, M.E. Inchiosa and A.R. Bulsara, "*Scaling laws for spatiotemporal synchronization and array enhanced stochastic resonance*", Physical Review E vol.53, no.3 p.2081-6 (1996).

A.R. Bulsara, M.E. Inchiosa, J.F. Lindner, B.K. Meadows, W.L. Ditto, N.K. Kasabov and G. Coghill, "*Noise-induced synchronized switching in coupled bistable systems*", Proceedings of the Second New Zealand International Two-Stream Conference on Artificial Neural Networks and Expert Systems p.10-14 (1995).

J.D. Neff, G.N. Patel, B.K. Meadows, S.P. DeWeerth and W.L. Ditto, "*Spatiotemporal dynamics of a stochastic VLSI array*", Proceedings of the 1998 IEEE International Symposium on Circuits and Systems (No.98CH36187) p.542-5 vol.3 (1998).

J.F. Lindner, A.R. Bulsara, B.K. Meadows and W.L. Ditto, "*Can Neurons Distinguish Chaos From Noise?*", International Journal of Bifurcation and Chaos vol. 8, no.4 (to appear).

Conferences Attended by Meadows (during grant period):

Third Experimental Chaos Conference Edinburgh, Scotland, UK, August 21-23, 1995.

Fourth Experimental Chaos Conference, Boca Raton, FL, August 4-6, 1997.

IEEE International Symposium on Circuits and Systems, Monterey, CA, May 31 - June 3, 1998.